Fuel Cell Vehicle Fleet and Hydrogen Infrastructure at Hickam Air Force Base

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INTRODUCTION

The US Air Force Advanced Power Technology Office (APTO) at Robins Air Force Base (AFB), Georgia, and the Hawaii Center for Advanced Transportation Technologies (HCATT) formed a partnership in 2001 to establish a National Demonstration Center at Hickam AFB in Honolulu, Hawaii. The Center's mission is to facilitate the demonstration and validation of the latest fuel-efficient and environmentally compliant technologies for use in ground vehicles, support equipment, Basic Expeditionary Airfield Resources (BEAR), and base infrastructure. This program supports APTO's goal of providing increased capabilities and benefits to the warfighter/customer, supporting the US Air Force Environmental and Energy Policy requirements, and reducing dependency on foreign energy sources with the insertion of Advanced Power Technology.

The Demonstration Center at Hickam is a leading activity in evaluating hydrogen as a transportation fuel. Acknowledging that fuel cells require much more development and that a hydrogen fueling infrastructure is virtually non-existent, the APTO/HCATT team set out to accelerate those developments and introduce the first fuel cell vehicles and hydrogen fueling station in both the Air Force and the state of Hawaii.

There are now four vehicles in a growing fleet of fuel cell powered vehicles operating at Hickam along with a modular, deployable hydrogen production and fueling station. This paper addresses the initial operation of the fuel cell vehicles and the supporting hydrogen infrastructure.

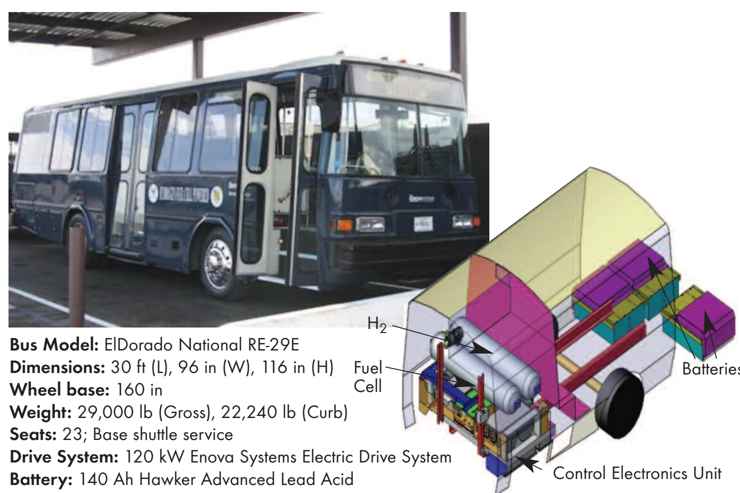
FUEL CELL VEHICLES

The four fuel cell vehicles include: a battery dominant, fuel cell hybrid electric 30 foot shuttle bus; a fuel cell hybrid electric step van; a fuel cell hybrid electric aircraft towing vehicle; and a new concept vehicle, which is a fuel cell augmented flightline maintenance support vehicle. Three vehicles use electric drive system components from the same manufacturer, and all four use fuel cells and hydrogen tanks from the same manufacturers. The commonality of components across various vehicle platforms demonstrates the potential for reductions in future acquisition costs.

Battery Dominant Fuel Cell Hybrid Bus

The first fuel cell vehicle, a 30 foot shuttle bus, was introduced at Hickam in February 2004. The 30 foot shuttle bus was selected to provide ample space for integrating the hybrid components. A small fuel cell was integrated with a large battery pack to minimize both technical and financial risks. Figure 1 identifies the components of the bus.

This shuttle bus was developed principally for operation on base, thus a range of 100 miles on full tanks of hydrogen and fully charged battery packs was considered sufficient. Battery-only range is 30 miles, to ensure the bus could continue to operate if the new technology fuel cell failed. Typically, the fuel cell keeps the battery packs charged; however, the bus is also grid connected and the batteries can be charged by plugging into a 220 volt



Bus Model: ElDorado National RE-29E
Dimensions: 30 ft (L), 96 in (W), 116 in (H)
Wheel base: 160 in
Weight: 29,000 lb (Gross), 22,240 lb (Curb)
Seats: 23; Base shuttle service
Drive System: 120 kW Enova Systems Electric Drive System
Battery: 140 Ah Hawker Advanced Lead Acid
Fuel Cell: 20 kW Hydrogenics Fuel Cell Power Module
Fuel Storage: 2 Dynetek 5 kg Hydrogen Storage Tanks (5000 psi); total storage – 10 kg

Figure 1. Battery dominant fuel cell hybrid bus.

About HCATT and the Partnership

HCATT is an element of the High Technology Development Corporation, an agency of the Hawaii state government. Since 1993, HCATT has managed several federally funded advanced transportation technology programs. Under this Air Force and state of Hawaii partnership there are three principal partners: APTO, HCATT, and the 15th Airlift Wing (15 AW) at Hickam AFB. APTO provides funding and program direction; HCATT, through contracts with private organizations, develops the technologies; and the 15 AW operates and evaluates the vehicles and equipment.

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14. ABSTRACT
The US Air Force Advanced Power Technology Office (APTO) at Robins Air Force Base (AFB), Georgia, and the Hawaii Center for Advanced Transportation Technologies (HCATT) formed a partnership in 2001 to establish a National Demonstration Center at Hickam AFB in Honolulu, Hawaii. The Centers mission is to facilitate the demonstration and validation of the latest fuelefficientand environmentally compliant technologies for use in ground vehicles, support equipment, Basic Expeditionary Airfield Resources (BEAR), and base infrastructure. This program supports APTOs goal of providing increased capabilities and benefits to the warfighter/customer, supporting the US Air Force Environmental and Energy Policy requirements, and reducing dependency on foreign energy sources with the insertion of Advanced Power Technology.

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(V) outlet using the onboard charger or plugging into an off-board, high-power fast charger.

Full operation of this bus using the fuel cell was initially delayed because of funding constraints resulting in a lack of hydrogen. Shortly after a hydrogen solution was achieved the bus was deployed for on-base distinguished visitors (DVs) transport. Hickam AFB welcomes a wealth of DVs, so this was considered an acceptable mission for performance evaluation. Bus duty cycles resemble that of urban driving.

One major problem surfaced early on. A drop in voltage occurred in one of the fuel cell stacks. The voltage irregularity was caused by a problem with the voltage sensor, not with the fuel cell stack itself. The problem was diagnosed and a solution identified. However, the fuel cell power module had to be removed from the vehicle and the stacks transported to the manufacturer for repair. An improvement in the production process solved the voltage sensing problem.

Typically, new technology vehicles undergo a one-year evaluation, but attempts are made to keep the vehicles in service as long as possible to provide a platform for further development and addition of technology improvements. As the first fuel cell vehicle under this program, this bus has experienced a few issues, some of which are a result of previously mentioned problems. It has recently had all the fuel cell stacks, the battery packs, and the control electronics unit (CEU) replaced. Following the replacement of the CEU, which involved the incorporation of new technology components, a communications problem with the fuel cell developed. This problem is currently being analyzed and, once resolved, the bus will be returned to service for further evaluation.

Fuel Cell Hybrid Step Van

The fuel cell step van was the second fuel cell vehicle introduced into the fuel cell vehicle fleet. The risk of developing a fuel cell dominant vehicle was much lower now because of lessons learned from the bus project. Major components of this van are identified in Figure 2. The van was only recently introduced to the base so limited performance data has been accumulated. This vehicle was developed principally for operation on base and it is designated for use by the maintenance squadron.

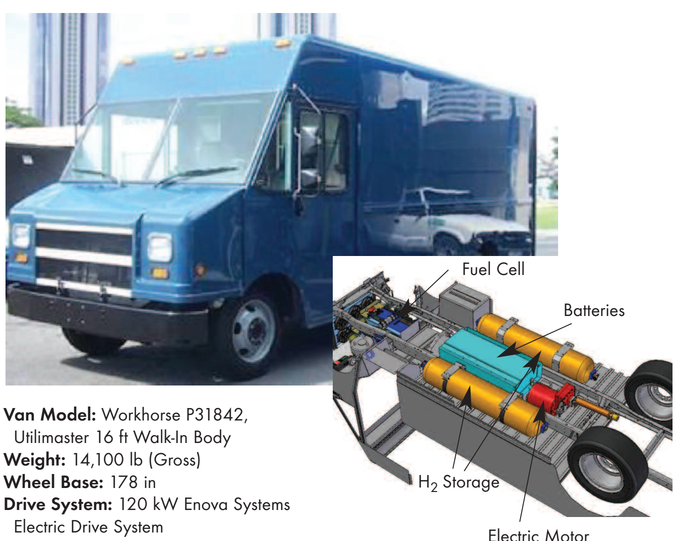
Initial diagnostic tests were run to ensure it met the performance specifications. Like the bus, the step van was configured to travel a minimum of 100 miles on base with full tanks of hydrogen. The tests demonstrated that this van has a 150-mile range (unloaded), not including the 42 ampere-hours (Ah) available from the battery pack. This van also features its own power generation capability, allowing maintenance personnel to plug their tools and equipment into 110 V or 220 V outlets (on board the vehicle) that are powered by the fuel cell.

Following a period of intermittent operation, performance degradation from the fuel cell power module in the van was observed; it was diagnosed and attributed to corrosion issues and crossover leaks. Essentially, aluminum oxide collected on the anodized endplate and anodized busbar in the manifold region of the fuel cell power module. To address this accelerated corrosion problem, the endplate and busbar were both redesigned to completely eliminate any metallic contact between the fuel cell process fluids and any stack components. Since implementing these changes, there has been no evidence of busbar or endplate corrosion in the manifold region.

The crossover leak was the result of a failed humidification device, which humidifies the hydrogen gas stream before it enters the fuel cell stack. There is a mixing of hydrogen and air in this device, and a crossover leak that develops within the humidifier can lead to a combustible gas mixture entering the fuel cell stack. This humidification device has been eliminated in the new technology fuel cell power modules. The metal ion contamination from the corrosion and the gas crossover leaks resulted in rapid degradation of the fuel cell membranes. Currently, the fuel cell stacks in this vehicle are being replaced.

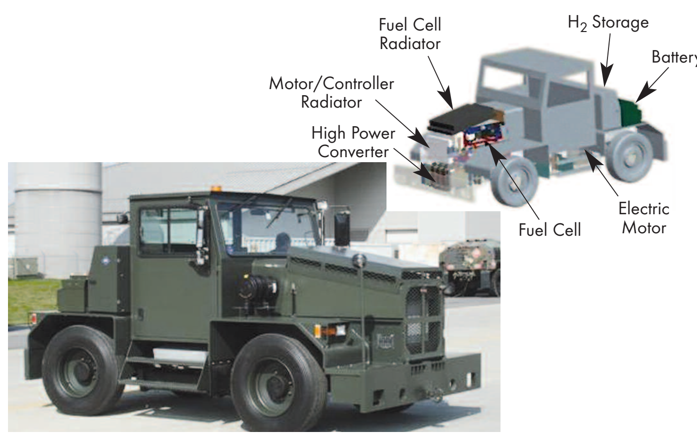
Fuel Cell Hybrid MB-4 Aircraft Towing Vehicle

The third fuel cell powered vehicle introduced to the fleet at Hickam AFB is an MB-4 aircraft towing vehicle. This vehicle utilizes the same fuel cell and electric drive system that were installed in the step van. The major components of the MB-4 are identified in Figure 3. This vehicle is operated by the Hawaii Air



Van Model: Workhorse P31842, Utilimaster 16 ft Walk-In Body
Weight: 14,100 lb (Gross)
Wheel Base: 178 in
Drive System: 120 kW Enova Systems Electric Drive System
Fuel Cell: 65 kW Hydrogenics Fuel Cell Power Module
Battery: 42 Ah Hawker Advanced Lead Acid
Fuel Storage: 2 Dynetek 5 kg Hydrogen Storage Tanks (5000 psi); total storage – 10 kg

Figure 2. **Fuel cell hybrid step van.**



Model: Entwhistle MB-4 Aircraft Tow Vehicle
Description: 14,000 lb Drawbar Pull, Four Wheel Drive; Four Wheel Steer
Curb Weight: 19,800 lb (stock)
Drive System: 120 kW Enova Systems Electric Drive System
Fuel Cell: 65 kW Hydrogenics Fuel Cell Power Module
Battery: 70 Ahr Hawker Advanced Lead Acid
Fuel Storage: 3 Dynetek Hydrogen Storage Tanks (5000psi); total storage – 7 kg

Figure 3. **Fuel cell hybrid MB-4 aircraft towing vehicle.**

National Guard Unit at Hickam AFB to tow F-15 fighter aircraft.

Initial operational testing is underway at Hickam. Early on, a major problem surfaced with the cooling system for the fuel cell power module. During operation the fuel cell would shut down prematurely due to an excessive increase in temperature. Using only 20 kW of power from the 65 kW fuel cell power module, the fuel cell shut down after about 42 minutes of operation. Initial diagnosis indicated the cooling components were not performing according to specifications. This was due in part to space constraints for installation of all the components of the hybrid drive system.

The fuel cell fan control system was improved to optimize the airflow, and a newly manufactured cowl above the radiator and engine compartment was installed to allow adequate air flow into the system. Additionally, a water circulation problem was detected. The system is circulating 20 standard liters per minute of water less than the specification required for the 65 kW fuel cell power module. Given that the batteries are the primary source for motive power and the fuel cell provides range extension, it was determined that 65 kW of output power was unnecessary for this configuration. The fuel cell was reset to operate at a maximum output of 30 kW. The 30 kW output of the fuel cell maintains the battery level while under continuous load, and the operating temperature is maintained well below the shut down temperature. Evaluation of the vehicle is ongoing.

Fuel Cell Augmented Flightline Maintenance Support Vehicle

The most recent fuel cell vehicle introduced is a new concept vehicle to support aircraft maintenance operations at remote sites. The project plan called for an all-electric drive platform complimented by a zero-emission generator to support maintenance on the flightline or at remote sites with no power, in keeping with the requirement for energy independence and the preference for zero-emission operations. An all-electric drive Ford Ranger pick-up truck was selected, but the bed was removed to facilitate installation of a newly designed utility bed. The new utility bed contains:

Model: Ford Ranger Electric Pick-up
Motor: 67 kW Siemens AC Induction Motor
Battery: 26 kWh Panasonic NiMH Battery Pack
Fuel Cell: 12 kW Hydrogenics Fuel Cell Power Module (APU)
Fuel Storage: 1 Dynetek Hydrogen Storage Tank (5000 psi); 1.8 kg
Equipment: 3 horsepower J-Air Compressor for Pneumatic Tools & Light Mast; 4 120 V (alternating current) Circuits, plus Retractable Extension Cord; 240 V AC Circuit; Pneumatic Light Mast Assembly

Figure 4. Flightline Maintenance Support Vehicle.

- A 12 kW fuel cell power module
- 1.8 kg of hydrogen compressed at 5000 psi
- A power bank consisting of four 120 V electrical outlets
- An additional retractable electric extension cord
- An air compressor for power tools with multiple coupling points including a 50 foot retractable air hose
- A removable pneumatic light mast with adjustable light module that can be extended by the air compressor
- A 220 V outlet for the light set, and an operator interface display to identify operations and faults

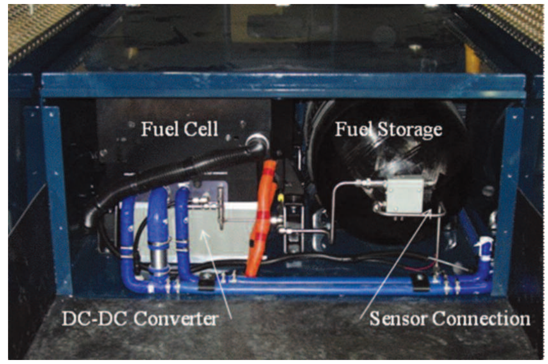


Figure 5. Fuel cell and hydrogen tank in utility bed; Operator Interface Panel in side compartment.

Figures 4 and 5 depict the major components of the Flightline Maintenance Support Vehicle. Evaluation of this concept vehicle has recently begun. All systems are operational and initial operator feedback is positive.

HYDROGEN INFRASTRUCTURE

The modular, deployable hydrogen production and fueling station is composed of Packaged Operating moDules (PODs), which are designed to be crush-proof, carbon steel packages for military or commercial transport. There are three primary PODs:

- Hydrogen Fuel Processor (H_2FP) using two Teledyne Energy Systems electrolyzers; production output 48 kg/day.
- Hydrogen Pressure Management (H_2PM) using a HydraFLX/Pinnacle intensifier to compress hydrogen up to 5000 psi.
- Hydrogen Pressure Storage (H_2PS) using nine Dynetek composite tanks; stores 50 kg of hydrogen at 5000 psi.

Two additional PODs provide power control and water for electrolysis; an MEP 9 generator is used to demonstrate deployment. Figures 6 and 7 show the installed station and its individual components. The deployable hydrogen fueling station serves as a model for other US Air Force installations and forward deployed bases.

The station began operating in November 2006. It was designed to accommodate fleet expansion, so the current demand for hydrogen on base is far less than the available output. Due to its deployable concept, the station was designed to be operated manually, and personnel on site operate the station and conduct vehicle refueling operations. A hydrogen fire safety and emergency response training course for base personnel was developed and made available for training throughout the Department of Defense.

The station at Hickam meets all applicable codes (fire, safety, electrical, etc.). It operates either from the electrical grid or the deployable MEP 9 generator. Connection to the power grid does not provide the most efficient means to produce hydrogen. However, the initial focus was to provide a safe and secure means of ultra-pure hydrogen production through electrolysis to meet the purity levels required for polymer electrolyte membrane (PEM) fuel cells while familiarizing military personnel with the use of hydrogen as a fuel and the handling of gas compressed at 5000 psi in vehicles. Two follow-on projects have already been

Figure 6. **Hydrogen production and fueling station PODs at Hickam AFB.**

initiated to add a 146 kW photovoltaic array and five 10 kW vertical axis wind turbines adjacent to the station to demonstrate the production of renewable hydrogen.

This station will continue to serve as a model for other installations. In this capacity, upgrades will be added as the demonstration and evaluation continue. Early modifications include: an upgrade to the H_2PM POD; the addition of an automated dispenser; and since the electrolyzers also generate oxygen, the addition of oxygen collection, compression, and storage for other uses on base.

Figure 7. **Hydrogen production and fueling station installed at Hickam AFB.**

FUTURE PROJECTS

By integrating fuel cell hybrid drive systems into a variety of platforms, HCATT was able to evaluate and overcome space and weight challenges and verify that various vehicles can perform to specifications. The hydrogen production station serves as a model for other installations and a basis for follow-on projects.

The program at Hickam AFB will continue to expand with additional fuel cell vehicles and upgrades to the hydrogen station. As indicated previously, the station is capable of producing more hydrogen than the current demand to allow continuing expansion and evaluation of the fleet. Some of the future fuel cell projects planned for Hickam include: a fuel cell powered light cart using metal hydride storage technology for hydrogen, another fuel cell powered shuttle bus, a fuel cell powered flightline sweeper, a fuel cell powered R-12 refueler, and a stationary fuel cell to power one of the buildings adjacent to the hydrogen station.

ACKNOWLEDGEMENTS

The author would like to thank the APTO for their foresight and emphasis on seeking solutions to energy independence while maintaining focus on meeting the needs of the warfighter. The APTO has provided us the opportunity to participate in this hydrogen fuel cell vehicle and infrastructure technology initiative, which is leading the way for advanced power applications in ground vehicles and support equipment in the US Air Force.

The author would also like to recognize the efforts of all of those involved in this program, including the following contractors: Hydrogenics, fuel cell manufacturer; Enova Systems, the systems integrator for the hybrid bus and van; Concurrent Technologies Corporation (CTC), the systems integrator for the hybrid towing vehicle and designer/developer of the Flightline Maintenance Support Vehicle; and HydraFLX, the designer/developer of the hydrogen station. Finally, the author would like to acknowledge the 15th Airlift Wing for their enthusiastic use and evaluation of the new technology vehicles and equipment.

Mr. Thomas L. Quinn has been the Director of the Hawaii Center for Advanced Transportation Technologies (HCATT) since 1994. HCATT is a division of the High Technology Development Corporation, a state government agency. HCATT, which was formerly known as the Hawaii Electric Vehicle Demonstration Project, was established in 1993 to represent one of seven regional consortia participating in the Defense Advanced Research Projects Agency (DARPA) Electric and Hybrid Vehicle Technology Program. This consortium continued to develop advanced transportation technologies under the follow-on US Department of Transportation Advanced Vehicle Technologies Program. Currently, HCATT manages programs for the Air Force Advanced Power Technology Office, which has established a National Demonstration Center for Alternative Fueled Vehicles at Hickam Air Force Base. Prior to this position, he completed a career with the United States Army, which included assignments as the Research and Development Officer for the United States Pacific Command and as a Program Manager at DARPA. Tom received his undergraduate degree from Penn State University and a Master's Degree in Management from Central Michigan University.